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Remarks on the Paper by Professor H. H. Turner; together with another suggested explanation of Stationary Radiant-points of Meteors. By Professor A. S. Herschel, M.A., D.C.L., F.R.S.

The mode of accounting for stationary radiant-points proposed in Professor Turner's paper certainly reveals to us in a most clearly expounded way, and in a very elegant and ingenious shape, a real *raison d'être* for their existence. We should not, of course expect coherence among the elements of a meteor-swarm so as to obliterate the Earth's deflecting action on the individual meteors and to allow a cluster, after the Earth's central passage through it, to resume its course with its radiant-point unaltered, but with a new position of its node impressed upon its orbit. But what would in that case be true for meteorites' individual deflections, that those which pass equally far from the Earth in front of and behind it receive from the Earth's attraction equal but opposite deflections which, in a cohering swarm, might be supposed to cancel each other, may be said of an individual meteorite, which will in a very long time pass as often behind as in front of the Earth, and will thus on an average undergo no material deflection. But through all these self-corrections the displacement of the node, of which Professor Turner has so well described and pointed out the existence and nature in his paper, is constantly renewed at each return, and thus goes on accumulating. A *vera causa* for the existences of such meteor-streams with fixed divergences and long durations, has thus been clearly traced; and though its

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action on swift-moving meteor-streams must naturally be slow, it may yet have sufficed, in long ages, to displace the nodes of some of the meteors of even those swift streams considerably.

We are assured, on the authorities of good observers, that the meteors from stationary radiant-points change their speeds progressively during the several months in which occasional flights of them sometimes continue to be visible, in perfect accordance, like the meteors of other streams, with the near or remote distances of their radiant-points from the constantly moving apex of the Earth's way, and that they accordingly present, in this way, even from a single radiant-centre, the same varieties of meteor-speeds as other meteors.

But the case differs in a stationary system of showers produced in the manner of Professor Turner's explanation; since from the permanency of both relative velocity and radiant-point of the meteor bodies' orbits during the Earth's shifting action on their nodes, a cluster of slow-moving meteors like, for example, the *Aquilids* in August, would remain a slow-moving one where their retrograded node is shifted round the Earth's orbit to April; albeit there, on the evidence of observers, the shower of April *Aquilids* is an extremely swift one: and there are many other such examples.

As much encouragement would be afforded to good meteor observations by any complete and satisfactory theory of stationary radiant systems, and as the difficulty of the quest for its solution makes lights thrown on this problem from as many different directions as can be obtained desirable, I will venture to describe a view to which I have been just lately led by thinking over Mr. Proctor's suggestive ideas ("Five Orders of Meteor Streams or Comets," *Monthly Notices*, vol. xlvi. p. 405, 1885, December) of the ejection of hyperbolic comets, and of enormously swift-moving shooting-stars from "giant suns like *Sirius*," as also some original illustrations published from time to time by Mr. W. H. S. Monck, of the mechanical conditions presented by this meteor problem.

Were cosmical streams of matter to be projected from large stars with such immense velocities that the Earth's orbital velocity and the Sun's attraction would both be insignificant quantities beside them, and were they to dash past the Sun and to produce on the Earth, as Mr. Proctor thought possible, the phenomenon of meteor-streams with radiant-points sensibly fixed and independent of the Earth's motion and position in its orbit, there can be no doubt that the enormous speeds of such meteors would have been long ago detected; and no such prodigious velocities of shooting-stars have, in fact, been ever yet recorded. But ages have passed by since the solar system assumed its present form, and many such visits may have been made to it in that time by streams of cosmical matter moving with such extremely hyperbolic velocities that the bodies' meteor speeds relative to the Earth in any part of its orbit might all be

regarded as nearly parallel in direction. The bygone epochs of such visits may have been when the Earth was still accompanied by a denser ring of bodies (perhaps like the annulus of matter round the planet *Saturn*) than any now to be found at the outer confines of the zodiacal light; and through such a ring of bodies, moving round nearly the same track, with nearly the same velocity as the Earth has in its present orbit, the cosmical stream might dash, expelling many members from the ring, as a tree is robbed of many of its leaves by a strong gust of wind sweeping through it; and it is here suggested now that it is the *débris* of such gusts, *not the gusts themselves* (as was originally suggested by Mr. Proctor in his above-mentioned paper), which we long afterwards, probably, behold showering down upon the earth as mixed comets and meteor systems with stationary radiant-points, the only visible chronicles, as we may say, remaining to us now of those long bygone celestial disasters.

The bodies struck out of their annular orbits had, before their dismemberments, velocities of their own nearly the same as the earth's orbital velocity; but, on receiving blows relatively directed from a nearly fixed relative radiant-point, they would compound the stationarily directed velocities of these relative blows or impulses with their own earth-orbital velocities, and would set off on new orbits round the Sun of very various sizes and shapes and degrees of inclination to the ecliptic. Were the gusts of cosmical dust possessed of ten or twenty times the speed which non-periodic comets have near the Earth's orbit, so as to dash past the solar system at rates of about 250 to 500 miles per second, and were a member of the Earth-ring to be overtaken directly *a tergo* by one of the cosmic dust-fragments, then, to convert it from a planet into a parabolic-pathed meteor-body, the ring-member's mass or inertia would require to be thirty- to sixty-fold the mass or inertia of the cosmic fragment, to allow the fragment's blow to add the needed 7 or 8 miles per second,* only, to the ring-body's original orbit velocity of about 18 miles per second. If below this proportion, the expelled body would receive a greater impressed velocity than this, and would never return in a closed orbit to its place of expulsion from the ring; but, if above it, the imparted velocity would be less, and the ejected body would describe a closed elliptic orbit round the Sun, and in the course of many returns to the Earth's orbit would probably be reabsorbed, in time, by the ring of bodies there; so that only ejected masses receiving nearly cometary velocities would, after the protracted length of time since that early solar system stage, be found returning now to the Earth's neighbourhood, either as shooting stars or, it might also even be, sometimes as comets.

It may be very fairly urged against these suppositions that

* Omitting, for the illustration, from the added speed, any further speed conferments required to overcome surrounding mass attractions.

almost any solid mass, however large, would be pierced through instantaneously by nearly any such impinging cosmic fragment, however small, and would suffer no deflection from its course; but the perforated matter would be carried forward, if not the mass itself, in the relative path-direction of the fragment, just as the luminous streaks of shooting stars pursue them on a straight course, and with all varieties of impressed velocities, through the Earth's atmosphere.

At each return of an ejected particle back to the Earth's and ring's route, if the Earth be struck and a shooting star produced, this meteor's relative or apparent radiant-point and actual meteor speed (or speed as apparent on the Earth), since the *Earth's* velocity is the same at the meeting-point as that which the *meteor* had there before it was ejected, must evidently be just the radiant-point and speed which were impressed on it by the blow with which the cosmic fragment struck it. That is to say, the observed radiant-point of all such meteors as compose the smoke and ashes of the ring, ejected from it by one single gust or volley from celestial spaces, will at any point of the Earth's course where it encounters such a meteor be the volley's relative radiant direction there, which has been assumed to be a nearly fixed, invariable one, from the volley's supposed enormously high speed of motion.

As regards the relative speed of the meteor as seen by observers on the Earth, since this, as was just now remarked, is precisely that with which the tempest of celestial missiles originally propelled the meteor, as a dust-flake in its wake, from some revolving masses of the ring, if we suppose this speed relative to the earth-ring (whether directed from the "quit" or from the "goal" of the Earth's way, or from anywhere between them), to have been just suitable (because that is a condition supposed to subsist among the generality of now occurring meteors), to launch the flakelet into space on some very long elliptic, nearly parabolic orbit, it is evident that on reappearing, after describing an orbit-circuit of such lengthy compass, as a meteor directed from just the radiant-point which the celestial volley's dust-scud first gave it, whether the radiant-point be near or far from the apex of the Earth's way, the accompanying apparent meteor-speed must necessarily be the theoretical parabolic-pathed meteor-speed for a radiant-point of the observed apex-elongation, and swift or slow accordingly, because it is the selfsame speed which, impressed originally on the meteoric flakelet, launched it on the parabolic path, or belonged in exactly this assigned relative way to an orbit of parabolic, or of very nearly parabolic form and compass. Thus both of the requirements of observation for a suitable solution of the apparently impenetrable fixed radiation problem are at least satisfied completely by this simply intelligible explanation (and perhaps not too far-fetched astronomical assumptions), that, in the first place, many ordinary meteor showers diverge with very prolonged

activities from nearly fixed radiant-points; and secondly, that, with the changing distance of the radiant-point from the apex of the Earth's way, the meteors of such a long-enduring shower also vary in velocity in exactly the same way as is found to be usual among other shooting stars and large meteors at different elongations of their radiant-points from that apex. But among the meteors proceeding from one single flight of cosmic matter, both short and long period orbits (though the first only very rarely) may be expected to present themselves: and the same conclusion therefore may be drawn from this hypothesis as the result shown above to be deducible from Professor Turner's theory, that among their intermittent outbursts both solitary meteors and meteor clusters might occasionally be found proceeding from a stationary shower's radiant-point with abnormally slow velocities.

All the knowledge that has yet been obtained by observation respecting the real velocities of meteors, appears, however, to be both too limited in extent, and too far from sufficiently reliable to furnish any very decisive and important test of these velocity assumptions, or of the correctness or incorrectness of a theory of meteor-streams' perturbations. The usually accepted view of the prevailing forms and mode of distribution of ordinary meteor-streams is, indeed, that their orbits are in general parabolic, crossing the Earth's orbit pretty equally at all points, and indifferently from all directions, with a nearly constant parabolic velocity of about 26 miles per second. Through this even distribution the northern side of the Earth should, by the latter's motion in the ecliptic, meet a maximum of meteor frequency in September and October, and its southern side a maximum in March and April, which has, however, recently been quite disproved by Mr. G. C. Bompas, in a paper on the "Semi-annual Variation of Meteors,"* where it was shown that a maximum meteor frequency in September and October, and a minimum frequency in March and April, appear by Dr. Neumayer's observations at Melbourne to occur just similarly, though somewhat less pronounced, in the southern hemisphere as they are found to do in northern latitudes. The rise and fall of frequency, in fact, seems rather to depend on a certain local concentration of meteor-radiant-points among the constellations rising after sunset in the east in autumn, which Mr. Denning found very decided indications of in 1886,† in a general catalogue which he then prepared, arranged in right ascensions, of more than three thousand radiant-point determinations. In the sector of R.A. from 0° to 60°, the crowding of shower-centres, increasing rapidly from both sides to that small quarter of the sky, is $2\frac{1}{2}$ times as dense as in the opposite similar sector of R.A. (180° to 240°), where a minimum shower-density is reached from both sides very gradually. The exceptional fulness in meteor showers of the former region

* *Monthly Notices*, vol. liv. p. 531–538, 1894 June.

† W. F. Denning "Distribution of Meteor-streams," *Monthly Notices*, vol. xlvii. p. 35–39, 1886 November.

seems to be certainly not ascribable to abundant watching of the sky in August for the *Perseids*, because up till midnight then, a considerable part of the productive area is not yet visible above the east horizon. As the whole tract is also, in the autumn months, about 90° from the apex of the Earth's way; and as the latter apex, from its northing at dusk to its rising in N.E. at 8^h–11^h, is never through the autumn evenings more than 15°–30° below the northern horizon, it seems unaccountable why a region so far from the apex as this particularly emissive sector is, should be more thickly strewn with radiant-points than neighbouring tracts of the sky in *Orion*, *Cancer*, *Gemini*, *Lynx* and the circumpolar constellations, all very well visible and so much nearer to the apex. But there is, besides, another law of distribution which no doubt helps to give this region a peculiar prominence in the wide autumn prospect round the meteor-apex, which was very strikingly illustrated and discussed not long ago by Mr. Denning,* that far the greater proportion of the radiant-points which produce fireballs and bright meteors, is collected pretty closely along the neighbourhood of the ecliptic; and the latter, we may now further add, lies nearly level along the eastern horizon in the autumn evenings.

Besides these signs of orbit-grouping, suggesting external actions on meteor-streams' positions of some very powerful predominating natures, the very varying results of meteor-speed determinations also throw considerable doubt on the supposed constancy among the speeds and parabolic forms of meteor-orbits. As regards meteorites, a thorough research of their known path-lines led Professor Newton to a conclusion † that the "large meteorites, or stones in the solar system, agree much more closely with the group of comets of short period than with the comets whose orbits are nearly parabolic"; and they are "nearly all direct moving, unless those moving retrograde are prevented by their great speeds, perhaps, from reaching the ground in a solid form." Of 116 observed meteoritic falls, he found that "109 must have been following, while only seven met the earth."

The shower of stones at Pultusk (near Warsaw, 1868 January 30), however, according to Dr. Galle, overtook the Earth almost directly with a sensible speed of 17 miles per second, exceeding that for a parabolic orbit by 7 or 8 miles per second.‡ And a detonating fireball of great size on 1873 June 17, also, like the foregoing meteor, well observed at the Breslau Observatory, was independently found by Dr. Galle and Professor v. Niessl to have been similarly overtaking the Earth, a little obliquely, in the plane of the ecliptic, with an apparently

* W. F. Denning, "Zodiacal Radiants of Fireballs," *Monthly Notices*, vol. lvii. p. 561, 1897 May.

† Professor H. A. Newton "On the Relations of the Orbits of Meteorites to the Earth's Orbit." *Amer. Jour. Sci.*, 1888 July—shortly referred to, as above, by Dr. Downing, *Monthly Notices*, vol. liv. p. 544.

‡ *British Association Reports*, 1868, p. 389.

hyperbolic orbit-speed which seems to have been about between 28 and 38 miles per second.*

Even for closely allied and perhaps identical radiant-points, good observations occasionally give very varying velocities. Thus on 1874 April 9, and 1876 April 10, two large detonating fireballs passed over Bohemia and Hungary, whose real paths were carefully deduced from many good accounts of each, by Professor v. Niessl, together with their radiant-points, at 19°, +57°, and 17°, +57°, and their real meteor-speeds, which were found to be respectively 14 and 25·5 miles per second. The former velocity agrees closely with, but the latter is nearly as large again as the theoretical speed, 14·5 miles per second, of a meteor from this radiant-point in a parabolic orbit.† On 1877 May 30, Mr. Denning, at Bristol, and Mr. Corder, near Chelmsford, simultaneously observed a *Jupiter*-like bolide, which ended with a streak and flash, rather low in the E.N.E. at both the stations. Both of the accounts were noted as "accurate," and the meteor's real path of 90 miles in "two seconds" (as described at Bristol), at a considerable elevation (87 to 75 miles) over the German ocean, was found from the observations, by Mr. J. E. Clarke, to have had a radiant-point at 20°, +58°, or (as I have now projected it again from the observed paths) at 22°½, +57°½, and the immensely high velocity for this radiant-point—nearly the same in place with that of the two last-mentioned aërolitic meteors—of 45, instead of 25 miles per second!‡

Another similar example was presented by the bright, long-pathed fireball of January 21, last year (1898), of which from thirty-three discriptions of its course, Mr. Denning found the apparent radiant-point and velocity, 130°, +30°, and 34 miles per second; *vide* his map of real meteor paths in 1897–98, in *The Observatory* of 1898, October. On 1877 January 19, a similarly bright and long-pathed fireball passed westwards from over Milford Haven to over the Atlantic Ocean south of Ireland, from three or four of the best descriptions of which I was able to deduce a real speed of 35 miles per second, and apparent radiant-point 135°, +27° (±6°), while by a new comparison of the accounts, Professor von Niessl assigned for the radiant-point a position at 135°·5, +22°.§

A splendid fireball passed with such a loud detonation over the city of Prague on the evening of 1879 January 12, that houses were shaken, and even, it was said, window-panes were broken there. Numerous accounts of this fireball, collected by Professor von Niessl, showed its real course to have been from

* *British Association Reports*, 1874, p. 270–276.

† *British Association Reports*, 1877, p. 144–47.

‡ *Ibid.* p. 143.

§ *Monthly Notices*, vol. xxviii. p. 228, and vol. xxix. p. 281, 1878 and 1879, February; and also for this and the next meteor's real path descriptions, *Reports of the British Association*, 1877, p. 118 and 153, and 1879, p. 83–84, and *Sitzungsberichte* of the Vienna Academy, 1879 May 8 (*vide infra.*)

across the north-eastern frontier of Bohemia, near Breslau, to a low height of nine miles, about twenty-five miles west of Prague, the apparent radiant-point and real speed of flight (uncorrected, like the other similar results here noticed, for the Earth's attraction) having been 133°, +19°, and 17 miles per second.

The parabolic meteor-speeds for these three meteors' radiant-points should have been 20, 23, and 26, instead of 34, 35, and 17 miles per second. But the slowest of them was the most distinctly aërolitic; and all their paths may be compared together briefly, with two cometary radiants, and with neighbouring recorded meteor-radiants of apparently two continuous shower-centres, in a table, thus:—

Cometary Radiants and Meteor-Shower Observers.	Dates of Shower-Nodes and of Cometary "Appulse" (☊). Shower I.	Shower II.	Cometary and Meteor Radiant-Points. Shower I. ° °	Shower II. ° °	Meteor-Speeds for Parabolic Orbits. mls. p. s.	Approx. Observed. mls. p. s.
S. Masters ...	...	1867 Dec. 12	...	136+30	37	...
J. Schmidt ...	...	December	...	130+30	(33)	...
☄ 1680 ☊ ...	Dec. 26	...	132+21·5	...	31·5	...
Fire-balls { Detonating	1879 Jan. 12	...	133+19	...	26	17
Silent ...	...	1877 Jan. 19	...	135+27	23	35
Silent ...	...	1898 Jan. 21	...	130+30	20	34
☄ 1833 ☊ ...	...	Jan. 27	...	135+25	20·4	...
E. F. Sawyer ...	1880 Feb. 6–8	...	130+22	...	16·5	...
G. V. Schiaparelli and G. Zezioli	...	Feb. 13	...	133+26	15	...

(Distinct showers from within 2° or 3° of position I., were also observed originally or deduced from foreign catalogues of meteor-paths by Mr. Denning, for February-March 12, and at frequent intervals between October 11, when Colonel Tupman recorded a shower in 1869, at 128°, +20°, and January 15. Some extension of shower II.'s duration was similarly traced by Mr. Denning in November and December, and by Mr. Corder in February-March; a shower was also noted in September by Mr. Greg, at 130°, +32°.) The two showers are included by Mr. Denning in his "Catalogue of 177 Apparently Stationary Radiant-points," *Astron. Nachrichten*, No. 3531, as Nos. 68, and 69, at 130°, +20°, October-January, and 132°, +31°, September-February; and the longitude and latitude positions are about 127°, +1°, and 125°, +13°. The Earth's apex, on January 15, was about 80° onwards in longitude from both the radiants, at about long. 205°.

Unless it is conceivable that meteor-orbits may by some disturbing action be shifted, as this table seems to indicate, sometimes forwards and sometimes backwards in their nodes, without change of their radiant-points or of their relative speeds of motion past the earth, it must be evident from these, and from many other such examples, that real lengths and durations of meteor-flights,

and consequently their real speeds, are not in general very certainly determined. But rather anomalous real speeds have yet sometimes been unmistakably observed, and if the interest which attaches to them were more generally felt, there is really nothing easier than to include in every note of a meteor's flight a pretty exact estimate of the time which the meteor occupies in its passage: this may readily be done by repeating mentally (at one's usual rate of clear articulation) as much of the monosyllabic English alphabet as represents the flight's duration, either during the short flight or directly after it, and at the rate of about six letters to a second, or four seconds for one whole alphabet, pretty minutely exact time-estimates of meteors' durations may thus be very easily recorded.

A small bright fireball, well seen by Colonel Tupman at Greenwich, and by Mr. Corder, near Chelmsford, shot on the night of 1877 November 27, at a low height of 56 to 13 miles over the English Channel, as was shown by Colonel Tupman, from the mouth of the Thames to a little short of the French coast near St. Omer. To describe this real path of 78 miles the meteor occupied, as Colonel Tupman noted attentively while it moved along, between 15 and 20 seconds, with a real speed, accordingly, little if at all exceeding, Colonel Tupman felt assured, about 5–6 miles per second. But he has calculated orbit-paths of this fireball around the Sun on both limiting assumptions, that its meteor-speed may have been either $5\frac{1}{4}$ or $10\frac{1}{2}$ miles per second.* Now a satellite of the Earth would travel (in vacuo) round the Earth's equator, or in a circle 100 miles above it, with a speed of 4·91 or 4·85 miles per second, in 84·4 or 85·5 minutes, and this was very near the lower one of the two assigned speed limits. But the meteor's course was inclined downwards 36° from horizontal, and could not have come from outside of the small sphere (not sensibly wider than a three or four days' journey of the Earth along its orbit), of the Earth's attraction with any less final speed of penetration into the atmosphere than about 6·9 miles per second, which nearly approached the mean between the chosen limits; for with any less observed final speed than this, the meteor would be kept constantly revolving round the Earth as a satellite, until it should chance to plunge into the atmosphere by lunar and solar perturbations and resisting actions, which actually befell this bolide when it was just at the node of the meteor-train of *Biela's* comet.

Thus the superior speed limit, or somewhere near it, and the second calculated orbit, will probably afford us, it would seem, the only obtainable approximation to this singular pathed meteor's real course about the Sun. But as in this native course the meteor almost overtook the Earth directly, and as the relative or apparent radiant-point was well shown to be near the pole of the

* *British Association Reports*, 1878, p. 270–73; and 1879, p. 84–5 (Mr. Hind's and Professor von Niessl's remarks on the meteor's real path and orbit).

ecliptic (about midway between δ and o *Draconis*), a considerable increase of the slow observed meteor speed might be admitted without materially affecting the deduced result that the orbits' form was nearly circular, overtaking the Earth very near its perihelion point, at just the node of the *Biela* comet meteors, with a slope of 20° or 25° to the plane of the ecliptic. On the appearance of these results in Colonel Tupman's paper above referred to, on "A Meteor of Short Periodic Time," it was pointed out by Mr. Hind* that excepting in the lengths of period and of major axis, the computed orbit's elements resembled very closely those of *Biela's* comet, which also, at its last appearance in 1852, overtook the Earth at this node with an inclination of about 12°, about 4° before its perihelion. There can be, therefore, little doubt that a large member of the *Biela* meteor-train had in one or two previous passages of the Earth through this meteor-ring been both reduced in speed and made steeper in its orbit's slope, to the ecliptic. But the apparent radiant's displacement through 55° from the usual position in *Andromeda* to near the head of *Draco*, or through nearly 70°, if the zenithal deflection in the observed path (acting at the last return *to just undo* some 12°, at least, of former deflection amounts in that direction) is allowed for, would require for its production not less than three close grazes, all in the same direction, of a *Biela* shooting-star, in front of the earth, each capable *in vacuo*, or unhelped by air-resistance, to bend the meteor's relative course past the earth through a maximum angle of about 24°. As no co-operating air-resistance in the last deflection, which was just opposite in direction to the previous ones' collective sum, can have brought about the large directional displacement, and as again no earth-deflections without the air's resistance could alter the relative speed of about 12 miles per second, with which the diverted *Bielid* would after each grazing passage continue to revisit and to pass through the Earth's attractive sphere again, from time to time, quite unretarded, a suggestion made by Professor von Niessl,† that resistance was the efficient agency in producing both this meteor's slow motion and the slow speed of the aërolitic fireball of 1877 January 12, seems, in this present meteor's case at least, to be very full of significance, as it seems hardly possible to explain, except by air-resistances in previous *rencontres*, how a meteor of even such a slow-moving star-shower as the *Andromedes*, could lose nearly half its relative or earth-regarded meteor-speed, and be deflected nearly 70° in apparent path direction from the well-marked relative radiant-centre of its parent meteor-current.

One more example of slow speed presented itself in a singular-looking bolide seen in south-eastern parts of England (at Worth-

* *Nature*, vol. xix. p. 484, 1879 March, and *British Association Reports*, 1879, *loco sup. cit.*

† *Sitzungsberichte d. k. k. Akademie* (Vienna; *Naturw. Klasse*), Vol. 79, May 8, 1879; and *Brit. Assoc. Reports*, 1879, *loco sup. cit.*

ing and Freshwater, London, Slough, and Tunbridge Wells) at about $9^h\ 15^m$ P.M. on 1898 August 21. As seen at Slough, it had a globular, bright green head nearly as bright as *Venus*, for half its course, which expanded without brightening then, and became kite-like with a short tail and outstretched wings, in length and width about $1\frac{1}{2}° \times \frac{1}{5}°$, and growing paler green or yellow as it moved leisurely, a little inclined downwards, through about 35° in all, in five well-timed seconds, to a point of gradual disappearance 20° or 21° above the horizon nearly due south. The time of flight was judged very satisfactorily, and could not have been more than 0·5 or 1·0 second under- or over-rated. The apparent paths at Worthing and Slough were also well referred to the stars, and the resulting real path was found to be 95 or 100 miles in length, from 61 miles over the coast of France, near the mouth of the Somme, to 21 miles high over a point 36 miles south of Brighton. The real speed was thus 19 or 20 miles per second, while for a parabolic orbit the speed for the real path's radiant point, near γ *Pegasi*, should have been 34 miles per second.

But a note, evidently of the same meteor, by an observer in Oise, in France, referring its path there to the stars, appeared in the *Bulletin de la Société Astronomique de France* of 1898 November (p. 473), which supplies a good control on the real path obtained from the English observations. It appears that the meteor's true course was certainly higher and further south, or more distant than had been computed, from the English stations; while the mean radiant-point, from the three accounts, at 359°, +10°, differs only about 4° from the precise point of intersection, at $2\frac{1}{2}°$, $+12\frac{1}{2}°$, of the paths mapped in England. By redetermining the meteor's real course with the help of the new observation, it appeared that it descended 123 miles in 5 seconds from 87 miles above Montdidier, Somme, in France, to 42 miles above the sea, 60 miles south from Brighton. The observed paths at Slough and Worthing required to be raised and lowered respectively (towards each other), $2°-3°$, and $3°-4°$, and the observed path in Oise to be kept as distant from them both, as the description given of it there by stars permits, to allow the three tracks to be combined compatibly together; so that it would be hardly possible to reconcile the three well-situated observations, without considerably overestimating the possible errors of the English ones, with greater heights than these (which agree well with the usual beginning and end heights of conspicuous-looking meteors), or with a longer path than 123 miles in 5 seconds, denoting a real speed of about $24\frac{1}{2}$ miles per second. For a parabolic orbit the meteor-speed from the adopted radiant-point should be 32 miles per second, and the utmost allowable range of the duration, between 4 and 6 seconds, would give a real observed speed somewhere between $20\frac{1}{2}$ and 31 miles per second, almost certainly less than the radiant-point's theoretical parabolic speed.*

* See note on page 194.

A succession of meteor-showers from an apparently long enduring and approximately stationary radiant-centre at about $5°, +10°$ (longitude and latitude about $8°, +7°$), has been recorded by several observers almost continuously from July to October ;* and it is with a certain small congeries of four of those showers, very accordantly observed by Col. Tupman and Mr. Denning, in 1869–85, close to that mean shower centre (at about $5°, +13°$, between August 18 and 25), that this meteor's path direction from about $359°, +10°$, or $2°\frac{1}{2}, +12°\frac{1}{2}$, on August 21, seems certainly, from its close proximity to them, to have been immediately connected. Now, as the apex of the Earth's way was then at about longitude 58°, or about 50° onwards from this long enduring meteor-shower's fixed radiant-point on August 21, and as the apex would recede further and further from this fixed point at later dates, any parabolic streamlet of the common radiant's swarm encountered in September or October would furnish slower meteors then than a similar constituent current of the swarm would do on August 21. But if it could creep back, in node, from the later to the earlier date without any change of either its apparent speed or radiant-point, the slow speed of this small green kite-shaped fireball of 1898 August 21, might then be sufficiently explained by supposing it to have belonged originally (just as in the above noted case of the large aërolitic fireball of 1879 January 12) to a parabolic meteor shower crossing the Earth's orbit on some later date (about 10° or 15° further on in longitude) than the marked shower group to which the bolide seems to have belonged, at $5° + 13°$ on August 18-25. The re-estimated speed of flight, of $24\frac{1}{2}$ miles per second, and the slightly altered radiant-point, corrected for zenithal deflection to $0°, +8\frac{1}{2}$, of the meteor's redetermined real path, gives the following elliptic elements of its short, but very eccentric orbit round the Sun :

Major and Minor Axes . . 2·098 and 0·545,
Aphelion and Perihelion distances, 2·062 „ 0·036.
Eccentricity, 0·9657 ; Motion, direct.
Inclination, 36° ; Anomaly, $-15°\ 35'$;
☊ $148°\ 47'$ Period, 392·5 days,
π $133°\ 12'$ P.p., 1898, October $3^{d}\ 4^{h}$.

With either this short elliptic or with a parabolic speed, this August shower-group's meteors approach the Earth's orbit from a real direction in solar space only a few degrees behind, and a few degrees above, or north of the antisolar point ; and the anomaly and perihelion distances of their parabolic paths differ

* Mr. Denning regards this shower as a long enduring stationary one, and has included it as No. 3, at $6°, +11°$, July–September, in his "Catalogue of 117 Long enduring, and apparently Stationary Radiant-points of Shooting Stars," in *Astronomische Nachrichten*, No. 3531, 1898 December.

very slightly ($-23°$ and 0·040) from those of the short-period elliptic orbit; so that only the periodic time and major axis of the orbit are greatly changed, in this instance (though the inclination of the parabolic orbit decreases also from 56° to 36°), by imparting to the meteor speed abnormal slowness.

It may be very probably conjectured from these few, nowise isolated or very exceptional, cases of speed determinations, that if all meteors are supposed to have been originally moving in parabolic orbits, some stationary radiant-points have pretty certainly appeared at times to produce meteors moving with velocities of abnormal slowness; and that among such slow-flighted radiant-centres some have also occasionally exhibited good examples of accordance with the node-translational theory's requirements.

In the two cases, only, reviewed above, of the fireballs of 1879 January 12, and 1898 August 21, which afforded such directly good agreements, the stationary radiant-centres happened to lie somewhat behind or westward from the eastward moving apex of the Earth's way; and a consistent explanation of the unusual slowness of those meteors' motions could on that account be easily presented, by supposing their nodes, in bygone times, to have gradually retreated to their now observed places, with fixed radiant-points and with constant meteor-speeds, from some slightly later original points on the ecliptic. For the Earth's apex, in ancient encounter-times, would there be more advanced, and therefore more distant than at the present nodal place, from the fixed radiant-points' directions; so that it would confer upon the meteors at their original ancient shower-dates, slower relative meteor-speeds—afterwards transplanted backwards with the nodes—than correspond parabolically with their present nodes and dates.

But for a slow centre's position in the other semicircle of longitude lying in front or eastward, instead of behind or westward from the Earth's apex, the explanation of slow speed which the node-displacement theory would furnish is considerably less simple; for in that case a node or shower-date anciently a little later, would signify nearer vicinity of the radiant-point to the Earth's apex, instead of greater distance from it, at the ancient, than at the modern encounter-time, or abnormal *enhancement* of the meteor speed by the node's backward journey, which is, of course, incompatible with progressive continuance of the node-displacing action, because a single such enhancement of a meteor's speed, by rendering its orbit hyperbolic, would withdraw the meteor for all future time from the Earth's vicinity. It may be added also, that the same reasoning obviously precludes attempts to attribute to these node-shifting actions any occasionally suspected abnormally swift meteor-motions, like those in the above table of the fireballs of 1877 January 19, and 1898 January 21, and of a few others of the above-noted fireballs, appearing to have had velocities exceeding those properly belonging to parabolic orbits. But, if it is not obligatory to

regard the node's excursion as confined to very moderate, restricted limits, a *still later* old-time shower-date may still, in this case also, be always chosen suitable for the node-shifting explanation, some measure of lateness *farther* on in its date than *just as far beyond* the time and place of the stationary radiant-point's apical culmination, or conjunction in longitude with the constantly advancing Earth's apex, as the latter is short of reaching the same culmination or conjunction point at the present-time date of the shower's encountering the Earth in the ecliptic. For the meteor speed being slower then by the radiant's greater elongation from the apex, at an ancient node so placed, than any which the shower should have at all the intervening points crossed by the node in its gradual retreat past the apex from its ancient to its modern place, it could never in the whole of that slow journey exceed or even continue to maintain (as it has at first) the shower speed belonging to a parabolic orbit, so that it would never escape from solar space, but would remain subject to the Sun's and Earth's attractions.

The same abated meteor-speed could not, however, be transplanted, either round many or round a single year's whole circuit from any place where the lower velocity is met with, except from some ancient-node place like that just described; because on its way from a remoter half-circle as its starting place, the shower's fixed radiant-point and meteor-speed would have to pass through one or more conjunctions with the Earth's anti-apex, and being swifter in its meteor-flights than stationary shower-speeds there belonging to parabolic orbits, its meteors would be thrown into hyperbolas and would never return again to the Sun's vicinity. In this way the Earth's anti-apex, in the very first circuit of a shower-node's revolution, acts as a stumbling-block in the way of all originally parabolic meteor-swarms' nodal translations, which must gradually sift them away from the Sun's attractive influence until only direct moving parabolic or long elliptic meteor showers are left, which will have their perihelia in the Earth's orbit, and inclinations not exceeding 45°; together with a very varied assemblage of stationary showers, consisting mainly of short-period meteors. For it is not known certainly, but only conjectured by proved analogies with comets, that the primitive orbits of ordinary shooting stars in general are approximately parabolic, and it is therefore allowable to suppose that some slow-pathed streams, particularly with radiants near the pole of the ecliptic, would not have their meteor-speeds raised above those for very long ellipses by their radiant-points' approaches to the Earth's anti-apex. The well-known stationary radiant-point at *o Draconis*, for instance, near the pole of the ecliptic, to which Mr. Denning assigns a duration of nearly the whole year, might belong to meteors moving either in nearly parabolic, in moderately long, or in very short elliptic orbits, and the dimensions, form, and inclination of the orbit would in every case, from the radiant-point's proximity to the pole of the ecliptic, undergo no

appreciable alterations by its node's attractive translation round the whole Earth path's circumference. For other long enduring showers in the same polar neighbourhood, orbits of considerable length and eccentricity might thus also be continuously shifted, without acquiring very different new forms and velocities; and it is pointed out by Professor Turner in his paper that, during the prolonged ages, and the thousands of slow returns which a shower-node's journey from conjunction of the apex to that of the anti-apex with its stationary radiant-point would embrace, the retarding action of a resisting medium might hold in check the growing lengths and velocities of the orbits sufficiently to retain any meteor swarms in closed orbits during their radiant-points' passages near the Earth's anti-apex, even if, as for an observed stationary shower near *η Persei*, or for others close to the ecliptic, the parabolic-pathed meteor-speeds range so far as from 12 to 38, or from $10\frac{1}{2}$ to $44\frac{1}{2}$ miles per second. If, perhaps, this resisting medium might be an extensive, rare atmosphere of the Earth itself, like what the "Bielid" fireball of 1877 November 27 seems to have encountered in the case of its reduced speed, and strong, partially neutralised deflections discussed above, the altered form of orbit might then present no hindrance or unsurmounted difficulty, which Professor Turner has regretfully intimated, to this view's acceptance; since the deformed orbit's node would still be in close proximity to the Earth's path, and in the meteor's repeated returns to it, the same retarding effect might be renewed, and the deflections eliminated by the meteor's passages on various sides of the Earth through its rare atmosphere.

I have endeavoured to compare the irregularities of radiation of the Perseid meteor shower with the probable effects of node-translation on the scattered meteor members of its series of showers, and the case presents, I believe, some satisfactory indications of agreement with this kind of node displacement; but from the retrograde orbit's steep inclination, of 80°, the secular disturbance of the node, or shower-date, gradually onwards, has probably been so slow as to be not far from comparable in its amount with the attractive translation backwards of the stray meteors' nodes (about 1° in 3,000 close encounters); so that occasional meteors from all the showers appear unpunctually before their proper shower-nights, intermingling with earlier showers, and lengthening their own chief dates' durations, and thus I have not yet successfully disentangled the complex results. But in its relations to observed velocities of meteors, the very originally suggested theory of node displacement which Professor Turner has advanced, and already largely and lucidly developed in his foregoing paper, seems to be sufficiently verified by the few examples of meteor observations which have been here quoted, and to have received a quite satisfactory general confirmation from these experimental cases. It seems hardly doubtful, also, that this sound and solid theory will hereafter be found to

be frequently in good accordance with the plentiful results of meteor-path determinations, when further and better trials and examinations are made of them by more extensively conducted comparisons of preserved accounts of their velocities and courses.

[P.S. (to p. 189).—The exact place of the French observer's station, near Attichy and Compiègne, in Oise, now kindly communicated to me by the acting secretary, M. G. Armelin, of the French Astronomical Society, really demands a slightly greater correction than that assumed, of the real path, in the above-found direction; and this must enhance somewhat the rather considerable errors which affect the observations. But if in the mist which there prevailed and greatly impeded accuracy of reference to two glimpsed stars in *Pegasus*, the description of the meteor's path at Worthing was perhaps considerably less accurate than the clear sky projections of the track at Attichy in Oise, and at Slough in England, a rather longer, and therefore swifter path than the above computed one, could be calculated, from a radiant-point at about 351°, +6°, or 353°, +7°, for which the parabolic meteor-speeds are only $28\frac{1}{2}$ or 29 miles per second; and the observed and theoretical meteor-speeds may not then have really been very materially at variance.—Note added, 1899 February 28.]

Observations of the Brightness of α Orionis, 1895–1898.

By T. W. Backhouse.

The accompanying table gives the results of observations of the brightness of *α Orionis* made at Sunderland with my naked eye, except where otherwise stated, from the beginning of 1895 to the middle of December 1898. The names of the stars with which *α Orionis* is compared are given at the tops of the columns, the number above each star being its magnitude taken from the Harvard Photometry, but in the case of ruddy stars (marked R), the magnitude is made ·22 mag. fainter, such stars appearing so much fainter to me than to the H.P. observers. Other stars observed are placed in the "Remarks" column. Columns 1 and 2 give the date and time (G.M.T.) of observation. Column 3 gives the relative atmospheric absorption. As the clearness of the atmosphere varies on different occasions, when an observation is made the apparent clearness, or assumed relative absorption, is recorded, being called 1·0 when it appears as clear as it ever is, or is likely to be, at the place of observation; 2·0 when the absorption seems double this, and so on proportionately, there being no superior limit to the scale. The average absorption in magnitude corresponding to the relative absorption is taken from tables computed from observations made since 1884; but if special observations were made on any particular night for the purpose of obtaining the absorption, a certain amount of weight is given them for modifying the average. Column 4 gives the magnitude calculated as equivalent to a difference of 1 step in